FUZZY LOGIC FOR DETERMINATION OF CRACK SEVERITY IN DEFENSE APPLICATIONS

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OUTLINE

- INTRODUCTION
- FUZZY LOGIC – AN OVERVIEW
- FUZZY SYSTEMS
- SYSTEM DESCRIPTION
- IMPLEMENTATION
- RESULTS AND DISCUSSION
- CONCLUSIONS

INTRODUCTION

- Some applications of interest & subject of research:
  - Ensure integrity of ceramic vehicle body armor support system (VBASS) [1],
  - Detecting through-thickness cracks in the steel box girders [2],
  - Inspection for fatigue cracks in cylindrically shaped component like helicopter rotor hub [3],
  - Evaluation quality of concrete evaluation [4].

INTRODUCTION

- Objective of crack detection:
  - Avoid the cost of unexpected breakdowns.
  - By determining remaining life & integrity of target objects.
  - Make a go/no go decision to use an armor plate.

- Applications of crack detection :
  - Crack location and orientation
  - The presence or
  - Severity of crack.

INTRODUCTION

- Meitzler et al [1] have demonstrated application of piezoelectric lead zirconate titanate (PZT) transducers to identify damaged from an undamaged plates.
- Objective of paper:
  - Defense application: crack detection in VBASS plates.
- Method:
  - Fuzzy logic to determine the crack severity in an armor plate.

FUZZY LOGIC – AN OVERVIEW

- Frequency domain & time domain analyses
  - captured sensors signals done to detect crack severity.
  - Expensive diagnosis.

- Lotfi Zadeh [5] introduced FUZZY LOGIC (since 1965):
  - Based on fuzzy set theory [5]
  - Used for fault diagnosis in many situations successfully.
  - Models human thinking process & natural language enabling decision making based on:
    - inconclusive information,
    - expert knowledge, and
    - thumb rules even for systems without any mathematical model.

FUZZY LOGIC – AN OVERVIEW

- FUZZY LOGIC generalizes classical logic which ,
  - Deals with Boolean values of true and false,
  - Facilitates approximate reasoning:
  - combining symbol manipulation &numeric computation

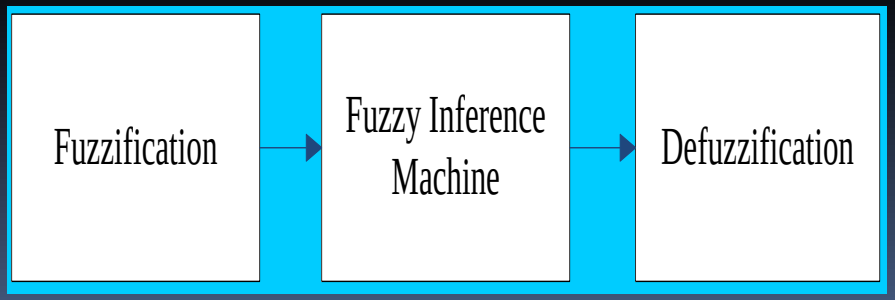
- A fuzzy set A defined on X is mapping from X to the unit interval [0, 1] denoted by

$$A = \{(x, \mu(x)) \mid x \in X, \text{ and } \mu(x) \in [0, 1]\} \qquad (1)$$

where μ(x) is a membership function, used to determine membership grade values between 0 & 1.

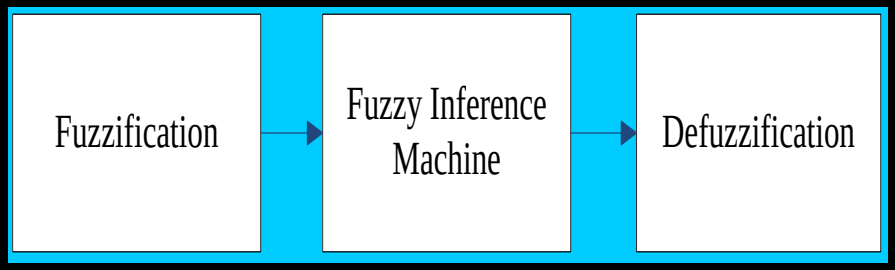
FUZZY SYSTEMS

- A fuzzy system uses
  - fuzzy logic to encode expert knowledge using rules and linguistic labels,
  - usually does not require complex mathematical model for design.
  - Fuzzy logic to create a nonlinear mapping of an input data vector into a scalar output [7].



Fuzzy system

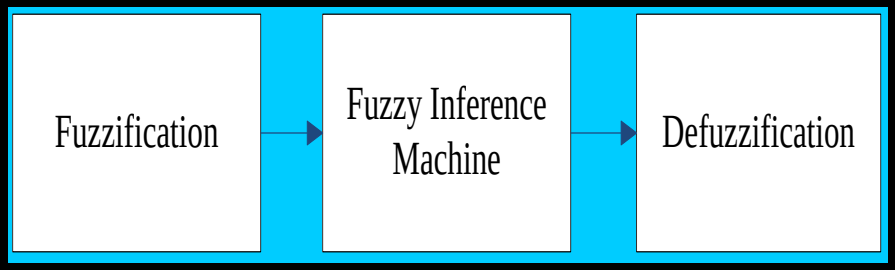
FUZZY SYSTEMS



Fuzzification :

- Achieved by assigning a singleton fuzzy set to the non-fuzzy inputs.
- allows the non-fuzzy values to be described as having a certain membership degree in the fuzzy set, which are mostly some suitable linguistic expressions or labels.

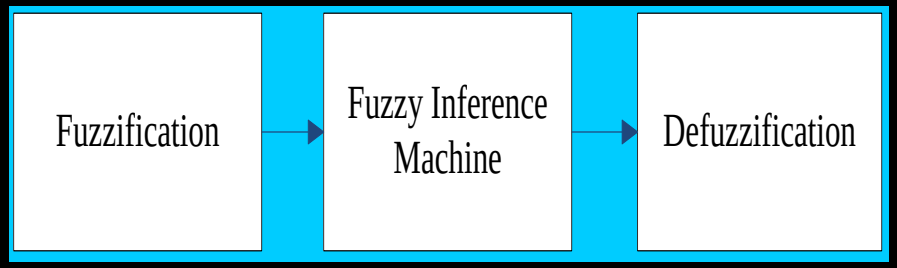
FUZZY SYSTEMS



Fuzzy inference machine:

- derives a fuzzy set of the output.
- Knowledge base consists of:
  - fuzzy rules,
  - membership functions used in fuzzy rules, &
  - a reasoning mechanism to perform inference procedure.
  - A simple fuzzy rule has the form: *If x is A, then y is B*, where A and B are linguistic labels defined by fuzzy sets.

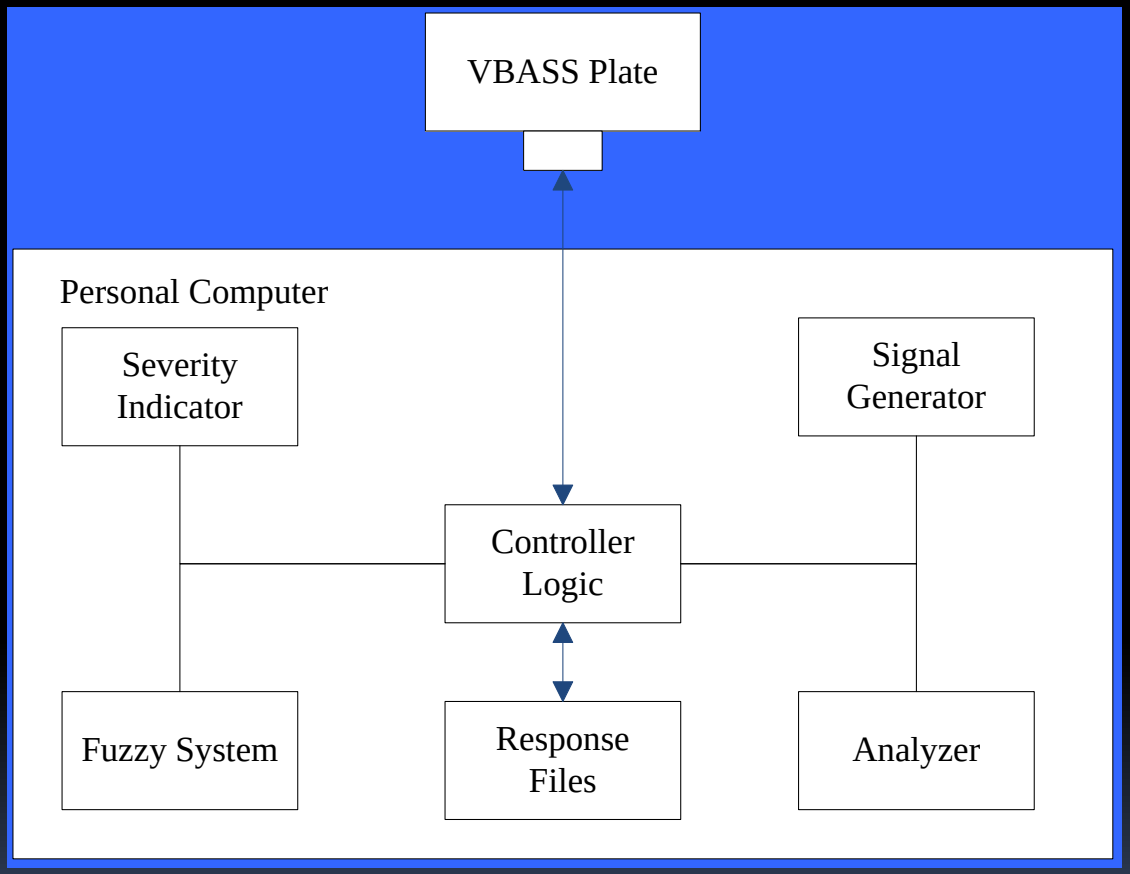
FUZZY SYSTEMS



Defuzzification:

- process of converting fuzzy output to crisp numeric output value.
- several Defuzzification methods available.

SYSTEM DESCRIPTION



Crack Severity Determination System

IMPLEMENTATION

- Dataset obtained from reference [1] by Meitzler et al.
- The dataset for three different test plates (undamaged, slightly damaged and severely damaged) consists of:
  - Frequency range of 1 KHz to 124 KHz.
  - Average RMS voltage , and
  - Standard deviation

IMPLEMENTATION

- Observed from Meitzler [1], the excitation signal of frequency in the vicinity of the resonance frequency of the test plate produces most distinct results.
- Used data for frequency range 63.5 KHz-77 KHz.
- Observed from Shashank's analysis[6], average RMS and standard deviations produced identical results.
- Only average RMS used for implementing fuzzy system.

IMPLEMENTATION

Table 1 - RMS and the Standard Deviation for the given range of frequencies.

0.00002428 (KHz)	Plate without crack		Plate with minor crack		Plate with severe crack	
	Avg. RMS	Standard Deviation	Avg. RMS	Standard Deviation	Avg. RMS	Standard Deviation
1 – 60	0.002971	0.0001889	0.002346	0.0001409	0.001099	0.00003229
61-90	0.032781	0.0001841	0.016029	0.0000551	0.000363	0.00003524
91-124	0.01117	0.0000554	0.010335	0.0000328	0.002088	

Table 2 – Average RMS for frequencies in vicinity of resonant frequency of test plate.

Freq. Range (KHz)	Average RMS		
	Undamaged Plate	Slightly Damaged Plate	Severely Damaged Plate
63.5-65.0	0.0318	0.0099	0.0037
65.5-67.0	0.0493	0.0143	0.0043
67.5-69.0	0.0666	0.0193	0.0045
69.5-71.0	0.0727	0.0226	0.0049
71.5-73.0	0.0595	0.0284	0.006
73.5-75.0	0.0209	0.0361	0.0056
75.5-77.0	0.0288	0.0243	0.0039

IMPLEMENTATION

Table 3 – Rearranged data
(Severity D = Damaged, S = Slightly Damaged, U = Undamaged).

Excitation Frequency (KHz)	Average RMS										
	0.005	0.01	0.015	0.02	0.025	0.03	0.04	0.05	0.06	0.075	0.1
64	D	S					U				
66	D		S					U			
68	D			S						U	
70	D				S					U	
72		D				S			U		
74		D			U		S				
76	D				S	U					

IMPLEMENTATION

Table 4 – Frequency labels.

Label	U	S	D
Severity	0	0.5	1

Table 5 – RMS labels

Label	RMS1	RMS2	RMS3	RMS4	RMS5	RMS6	RMS7	RMS8	RMS9	RMS10	RMS11
RMS	0.005	0.01	0.015	0.02	0.025	0.03	0.04	0.05	0.06	0.075	0.1

Table 6 – Severity labels

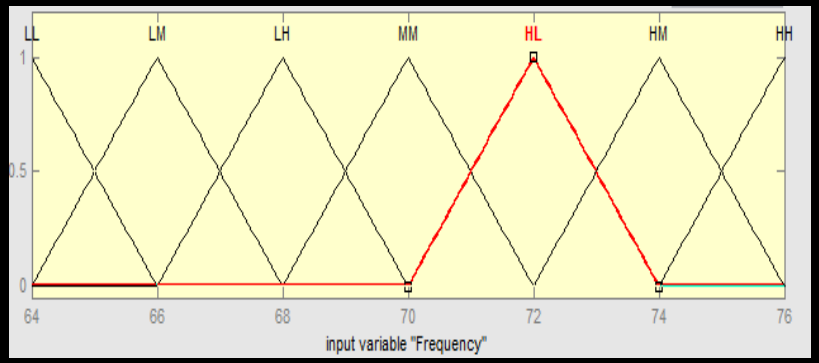
Label	LL	LM	LH	MM	HL	HM	HH
Frequency (KHz)	64	66	68	70	72	74	76

IMPLEMENTATION

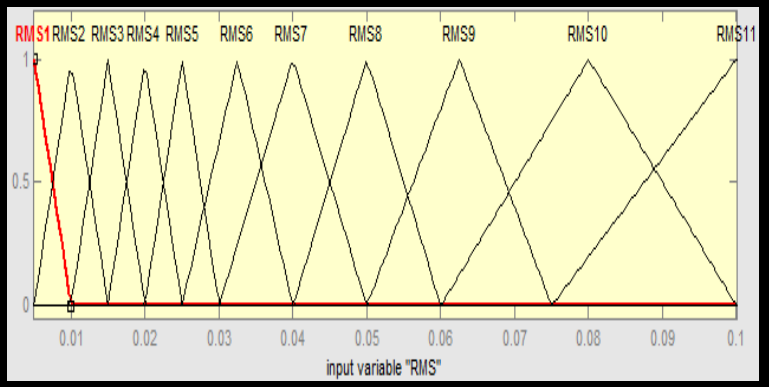
- Fuzzy System Design Steps:

1. Determining the input and output variables
    1. input: excitation frequency (Frequency) and average RMS (RMS) and
    2. output : severity of plate damage (Severity).
2. Determining the universes of discourse – based on Table 3,
    1. Frequency's - [63.5, 77] and
    2. RMS - [0.0037, 0.0727].
3. Determining the linguistic labels –Tables 4, 5 and 6.
4. Triangular membership functions : to fuzzily the crisp input and output values. Some other choices of membership functions – Trapezoid, Gaussian, Bell curve etc.
5. Framing linguistic rules – based on the Table 3, we formed the following rules:

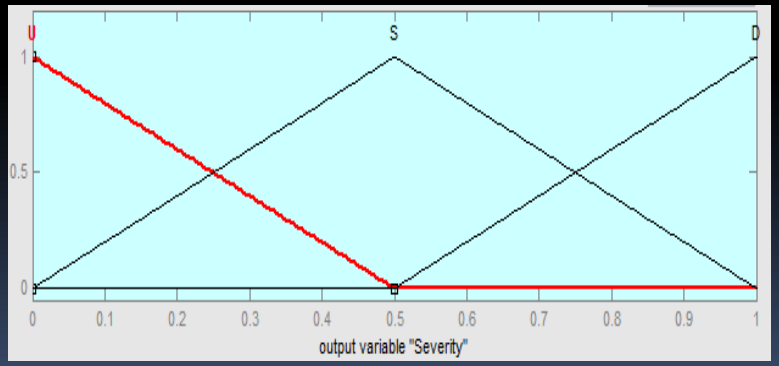
IMPLEMENTATION



Input variable Frequency

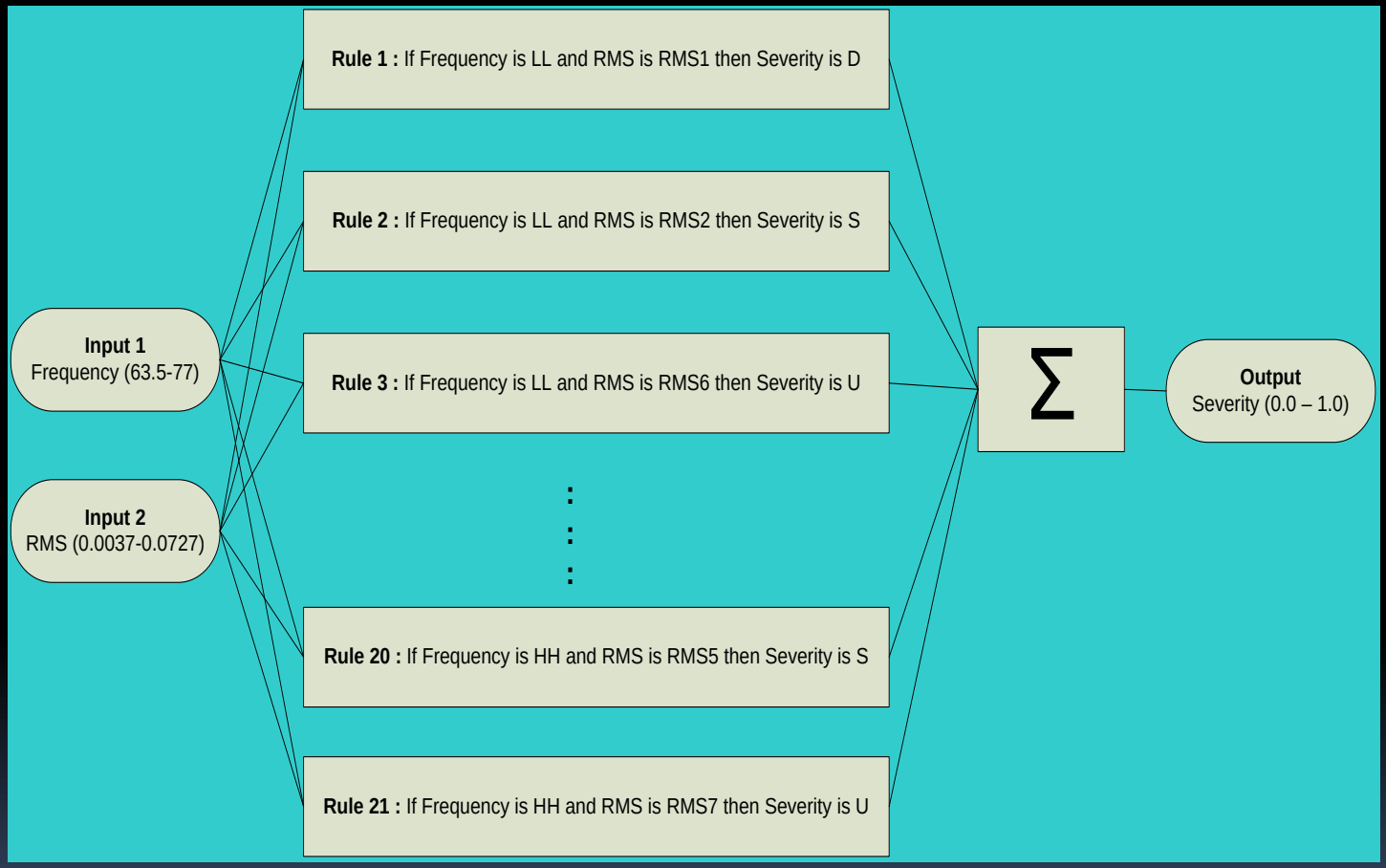


Input variable RMS



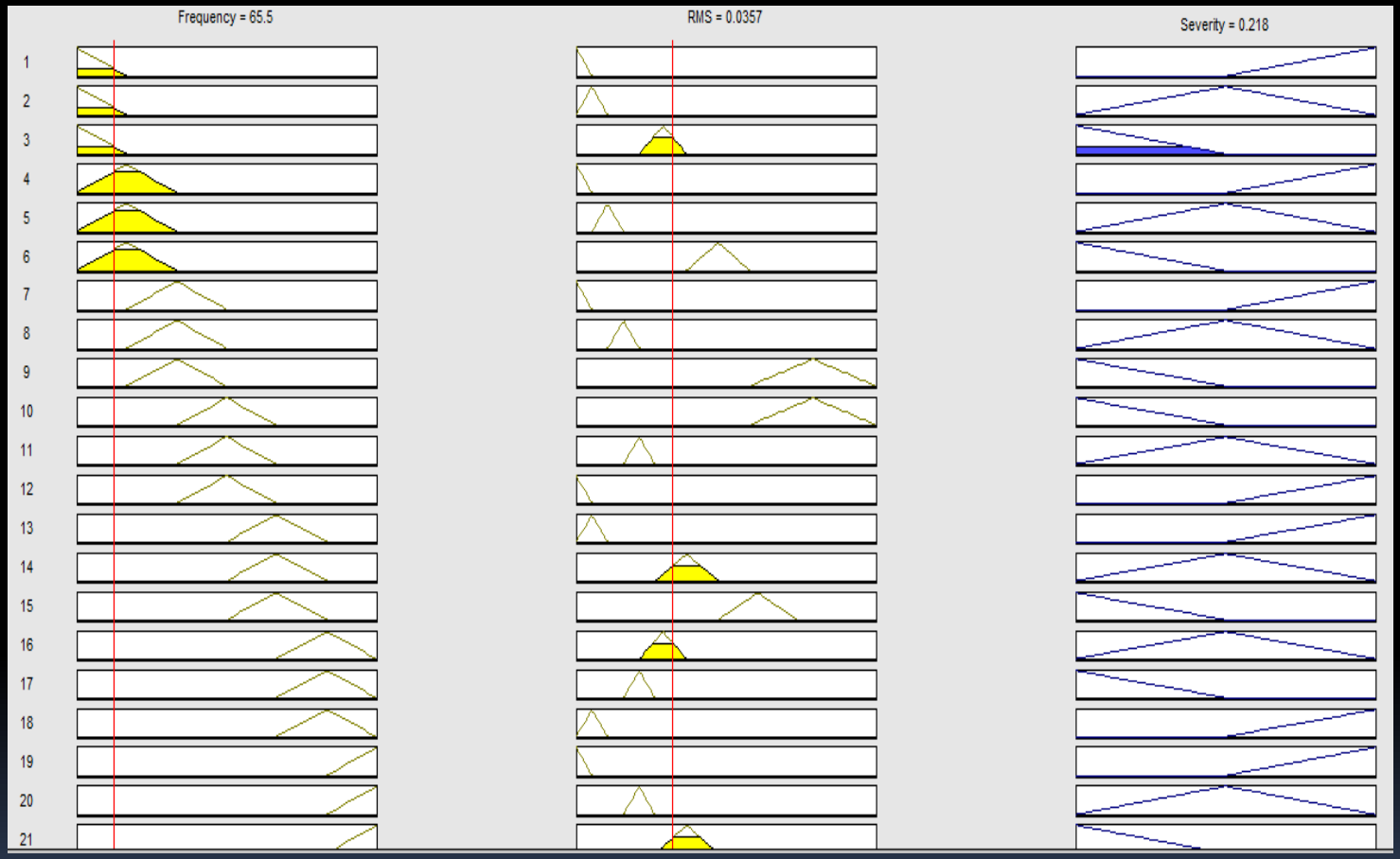
Output variable Severity

IMPLEMENTATION: System



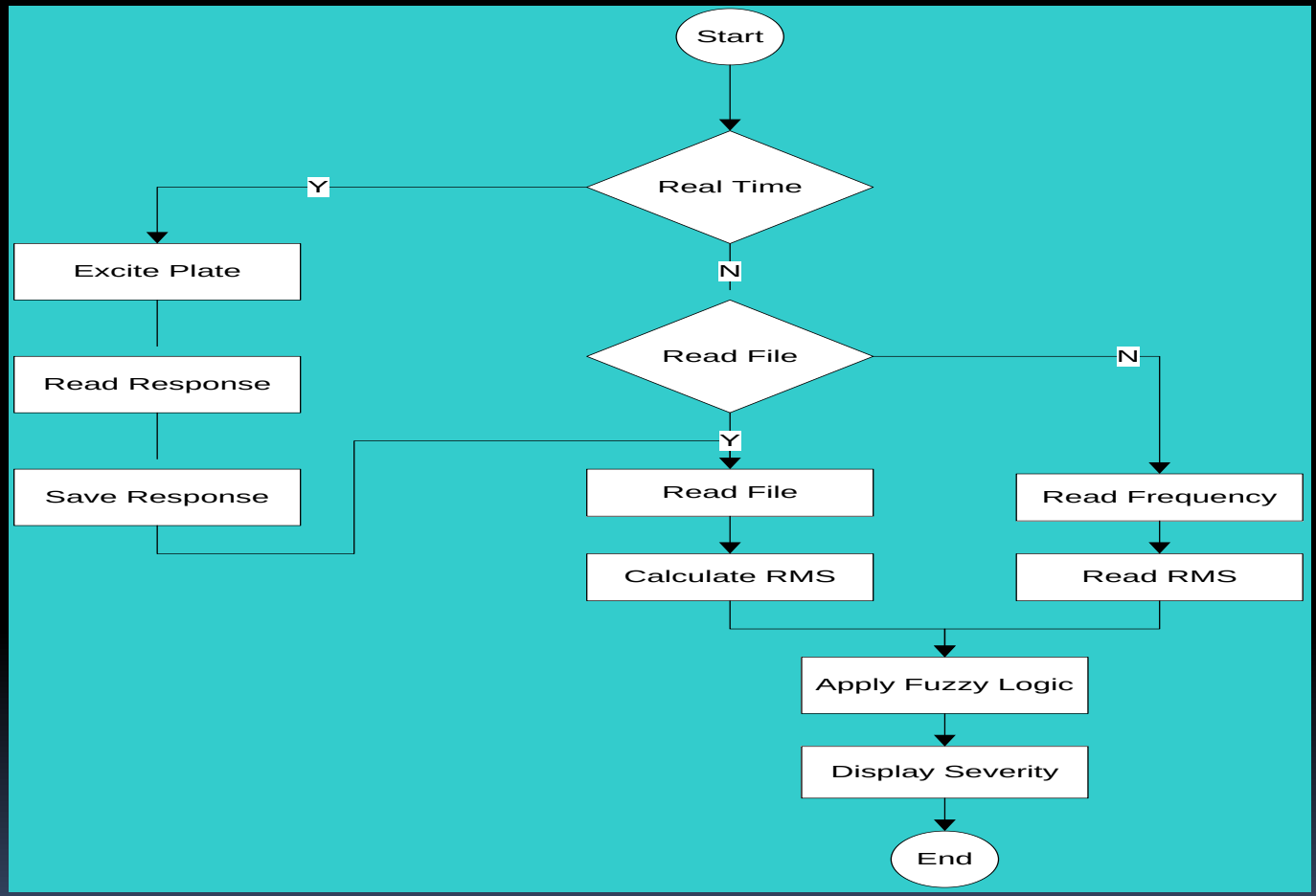
Rules showing the relationship between the input and the output

IMPLEMENTATION: System



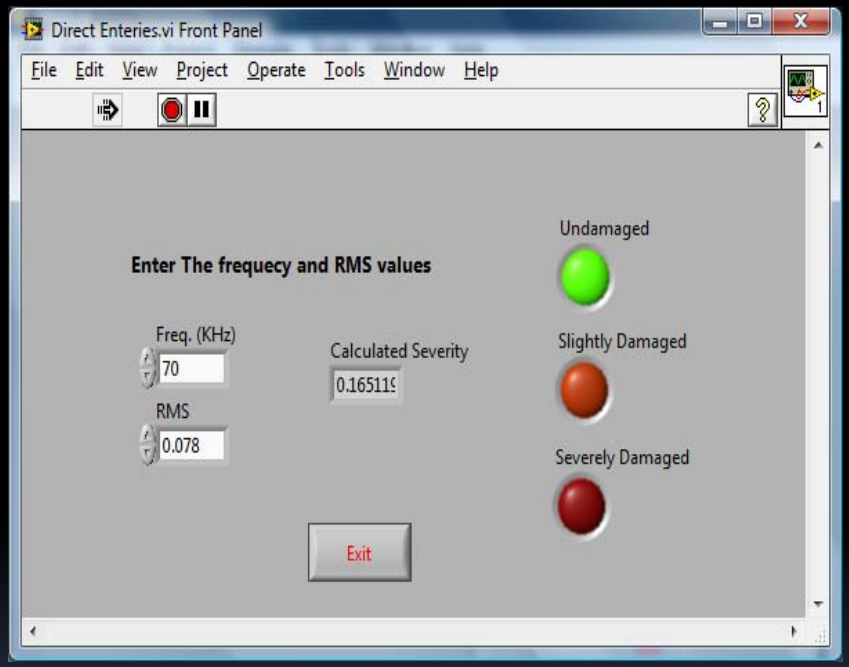
The inferred simulation output of the system:
Frequency = 65.5 KHz and RMS = 0.0057,
Calculated value of severity = 0.218, Interpreted = no damage

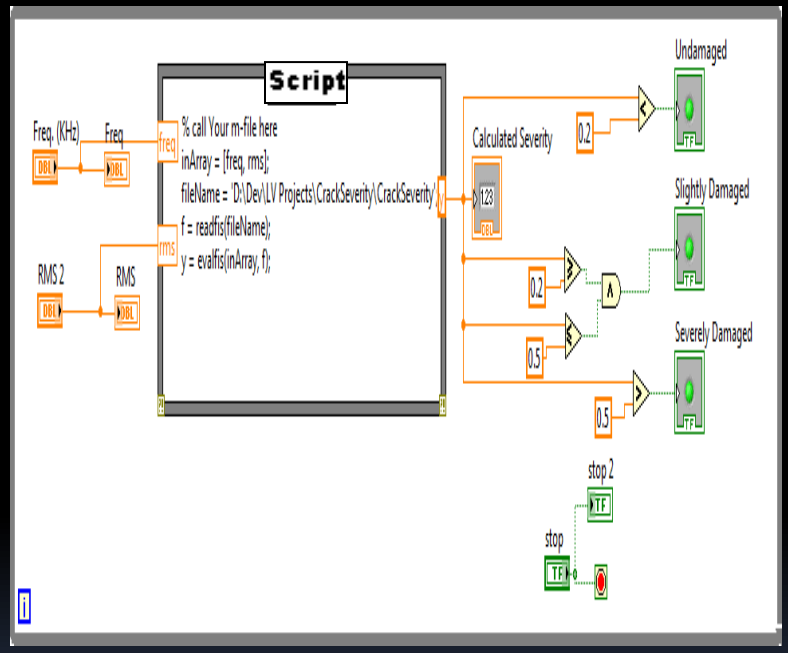
IMPLEMENTATION: System



Flowchart of the system

IMPLEMENTATION: System





Software implementation of the system

RESULTS AND DISCUSSION

- A low cost approach presented to make *Go/No Go* decision for using VBASS plates.
  - System implemented on a PC with software.
  - External hardware : Data Acquisition System.
- If relative size of crack is important:
  - recommend more labels for average RMS, and severity.
- Approach not useful for determining exact crack size.

RESULTS AND DISCUSSION

- Dimensions & material of test plate need to be same as plates used for implementing fuzzy system.
- Did not study effect of location of damage in a plate.
- Single PZT sensor set-up:
  - Location may have an effect on result,
  - A small damage close to the sensor may be detected as severe damage or
  - A severe damage away from sensor may be detected as slight or no damage,
  - Recommend set of three PZT sensors at different locations & average of three RMS values be used for calculations.

CONCLUSIONS

- A fuzzy approach to implement a non-destructive system to determine the severity of cracks in plates presented.
- Fuzzy approach is useful
  - mathematical model of the system is not available
  - or the data available is incomplete for detailed analysis and design of the system.
  - With satisfactory results for a fraction of cost, efforts and time.
- A prototype of the proposed system:
  - simple and
  - low cost solution for only a Go/No Go decision.

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THANK YOU!